Working Group on Engineering Training and
the Requirements of Industry

Report to
the Committee on Manpower Resources
for Science and Technology

Education and Training requirements for the electrical and Mechanical Manufacturing Industries

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The Problem and its Significance

1. To generate and maintain technological progress and rising productivity industry needs engineers, scientists and technologists; they make possible economic advance. They also form a pool of talent from which future leaders and managers may be drawn. Their effective deployment and utilisation have come to be recognised as important factors in the nation's economy.

2. In considering these issues the Committee on Manpower Resources for Science and Technology, in its first report,* drew attention to the probability that, as a growing proportion of those entering science and technology received a university education, more would be oriented, as higher education now stands, towards theory and research and away from the art of design and production. But industry will increasingly have to recruit from the university streams for those activities of development, design and manufacturing which were staffed in the past by men qualifying through longer and more traditional industrial routes.

3. The true role of the engineer is to design, organise and create—to practise an art based on science. We detect a shift of interest at present away from the art to the science which must underlie it. The balance must be restored, and the full preparation of the practising engineer requires that the teaching of the science be combined with the best features of the traditional teaching of the art. Our concern is to ensure that this is done as effectively as possible. The university undergraduate course rightly concentrates on the science, and in this case the process must be completed at the postgraduate level. There is ample evidence that present schemes for achieving this are unattractive to many graduates. This, coupled with the bias towards research, which is often more readily satisfied outside industry, accentuates the main problem of increasing the flow of the more able graduates into industry.

4. Some parts of industry have found a partial solution to this by using, as a point of entry, their research and development departments, the environment of which often resembles that of a university research department. This method of induction offers the graduate a more acceptable but limited introduction to industrial problems and functions. Such a solution can be appropriate for the science-based industries with a large research and development effort, but even in these industries it does

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*" A Review of the Scope and Problems of Scientific and Technological Manpower Policy ", (Cmnd. 2800), October 1965.

not afford a sufficiently rapid or effective flow of scientists and technologists into design and manufacturing. The problem is more acute in traditionally-based industries whose main need is to increase rapidly the numbers of highly qualified men with a good scientific background in their design and production activities. A more positive attempt to bridge the gap between educational supply and industrial needs is urgently required. We believe the task of devising a "*matching section*" to be the most pressing problem before us, and we propose below how this might be attempted (paragraph 14).

5. In our view a solution of this problem must attempt two tasks. First, it must achieve the most efficient conversion of the graduate into an effective industrial technologist, making the best use of his educational background and maintaining his interest and enthusiasm; second, it must succeed in attracting a higher proportion of the ablest graduates into industrial employment. A successful solution must embody the conviction that design and production offer challenges and satisfaction every whit as great as those of research and development—for scientists as much as for engineers and technologists.

Analysing the Requirements

6. There are numerous routes to higher technical qualification with differing chronological arrangements of industrial and educational experience. The matching section can and must assume a variety of forms depending on the nature of the route and of subsequent industrial employment. It is nevertheless possible to distinguish the broad features which must characterise a successful solution. It must:

(*a*) satisfy the employer's requirements while recognising the wider aims of education;

(*b*) take account of the graduate's personal qualities and motivation and of his desire for early responsibility;

(*c*) be designed and constructed jointly by education and industry;

(*d*) make the best use of educational and industrial resources in the national interest.

7. As an illustration we have selected the case of the graduate entering manufacturing industry after three years at university. The universities will be a major source of supply of qualified scientific and technological manpower over the next few years; moreover this route offers a clear exposition of the main features of our proposals. Nevertheless in choosing this example we would not wish to imply that we consider this to be an optimum arrangement; indeed we see advantages in each of the alternative routes.

8. To a varying extent education prepares the student for a career; industry requires a man for specific technological tasks. The boundaries of academic disciplines differ from those which characterise industrial appointments. The matching section must achieve a transition that takes account of these inherent differences. At first sight some advantage might appear to be gained by increasing specialisation in undergraduate courses but this has major disadvantages. It requires a decision by the student when he has little if any knowledge of industry; moreover, such specialisation must inevitably be at the expense of his broader education in fundamentals. An early choice of specialisation demands a longer "lead time" for

forecasting industrial needs; and a wrong choice could impede the graduate's subsequent progress and mobility. We therefore favour the alternative approach which postpones a decision on specialisation in full-time courses to the graduate level and permits greater concentration on more fundamental matters at the undergraduate stage.

9. In this approach the new graduate will have a broad background of engineering science and of some associated technology appropriate to the academic discipline of his degree—electrical engineering, mechanical engineering, or physics. He will have been accustomed to solving single-topic problems of a theoretical kind with a unique solution, on his own and without collaboration. By contrast his first responsible position will be characterised not by an academic discipline, but by a field of engineering—such as computers, electrical switchgear, or micro-electronic devices. It will be in a severely practical rather than in an academic environment. The geometrical concept of a straight line now becomes a difficult reality, and such concepts as weightless rods and frictionless pulleys give way to things endowed with that " cussedness of inanimate objects " familiar to all engineers.

10. The graduate will find that jobs are based on several functions—research, development, design and engineering, manufacturing, commercial—one of which will usually be dominant; but only research may already be familiar to him. His approach to problem-solving must now change radically. He must learn to take part as a member of a team in solving multi-topic problems to which there are no unique solutions but rather several optimum answers, to be resolved within strict limits of time and money. He must be made familiar with how things can be made, with the properties of materials and the principles of manufacturing. He must also learn to do his job as a member of an organisation, within the customs and practices of the company and of the industry as a whole. These differences and requirements give some indication of the kind of knowledge, attitudes and experience which the graduate must acquire.

11. There is however a further important step which must be taken—the decision on the graduate's first appointment. On the one hand he must decide in which field of engineering his technical interests lie and which main function best suits his aptitudes and temperament. On the other, his employer has a responsibility to determine where the graduate's talents can be most effectively used. Both employer and graduate are involved in a decision on first appointment, to be made perhaps halfway through the period of training. This decision will in turn determine the specialised education and training to be given in the final period.

12. So far we have been mainly concerned with the employer's requirements but the process of assimilation is necessarily a partnership between employer and graduate. The common aim is to get the graduate into his first job, as quickly and effectively as possible. His interest must be caught and held by the challenge of problems which match his ability and extend his experience in a planned programme of education and training which will command the graduate's esteem no less than that of other postgraduate activities which were open to him—for example, that of research leading to a higher degree. The graduate must also gain confidence through the practice and use of his newly acquired knowledge and techniques in real life situations.

13. We identify in this analysis the following main elements of education and training:

(i) instruction in the customs and practices of the particular company and of the industry as a whole:

(ii) instruction in the principles of manipulating materials and of making things, i.e. manufacturing engineering:

(iii) re-orientation of approach to problem-solving:

(iv) specialised knowledge relating to *main function* and *field of engineering*:

(v) organised experience in using newly acquired knowledge in the practical conditions of manufacturing industry.

Design for a Matching Section

I. Main Components

14. We propose that the elements defined in the last section might be provided by four main components of education and training:

(i) A course in the principles of manufacturing engineering:

(ii) A design and manufacturing group project—a microcosm of the industrial situation:

(iii) A specialised course in product or manufacturing technology:

(iv) Industrial experience—organised exposure to the industrial environment.

(i) *Manufacturing Engineering*

15. There is a limit to what can be taught in a degree course, whether full-time or sandwich, and the emphasis given to the principles of engineering science is in our view correct since it is on these foundations that technological advance is based. The degree course may inevitably lack something of the principles of manufacturing engineering—the choice of materials for a given purpose and their manipulation into required shapes. In practice the graduate is too often left to abstract these principles from his untutored and perhaps indifferent observation and experience on the workshop floor. His time is apt to be wasted, he then becomes bored, and his drive is sapped. Only the most determined will wring from this experience a feeling for what can and cannot be done, for the limitations and advantages of each process. Many good men will seek careers elsewhere. Yet these principles provide an essential grid of reference by which the young engineer may chart a profitable course through the problems of his professional life. Materials and their manipulation exert a profound influence on all stages of engineering process from design to manufacturing, determining not only whether something can be made but whether it can be made economically.

16. We believe that the benefits of this basic experience on the workshop floor can be given in a way that appeals to the intellect by extracting and codifying the principles of manufacturing engineering and by presenting them in an educational setting while maintaining intimate contact with industry. The graduate will also acquire sufficient manual dexterity and insight into the basic engineering operations to question long established practice with some degree of confidence. Such a course

might include: the practical three-dimensional geometry underlying the design and use of machine tools, the increasingly varied processes by which materials may be formed or cut, the properties of materials related to their structure, and the way these determine how they are manipulated or joined.

17. There are already several courses which discharge in part the requirements envisaged here and we would commend them as a first step towards what we consider must be a very much greater provision of opportunity on a national scale. All university graduates entering employment in this sector should have had access to a course of the kind we envisage. It can be short and requires only modest facilities. It could be mounted at a local college or university wherever there are sufficient students to make the course viable, or it could be set in industry. To assist this development we thought it desirable to appoint a Sub-Committee to establish in greater detail the contents of such a course. Their report is presented in Annex A. We would particularly draw attention to the Sub-Committee's finding that staffing is the key to success of such courses. Structure and presentation must match the graduate's approach and background and maintain the pace of work to which he has been accustomed, and this will require staff of high calibre.

(ii) *Group Projects*

18. To give a group of 12 young graduates three months out of college, a sum of £600, the normal access to the manufacturing facilities of a firm, and an order for a cam grinding machine to be in operation within 14 weeks might seem an intemperate act of faith. Yet there is by now ample evidence that young men placed in such a microcosm of practical industry respond with enthusiasm and ingenuity. They must organise themselves, delegate activities, apportion time, money and skills—in fact, manage a technical-machine-human complex. They will learn that poor communication costs time and money; that it may be cheaper to buy a component than to make it but that it often comes late or is out of stock. They will learn that the designer who gives no thought to his colleagues whose job it is to manufacture and assemble the article does them a disservice that their skills and ability can never entirely rectify.

19. We are convinced from the evidence we have received that there is no more effective way than the group project for induction into the manufacturing ethos. It satisfies the graduate's wish to do something constructive; it provides an opportunity for him to use the skills and knowledge he has acquired, to convert ideas into hardware; and it extends the grid of reference by which he can evaluate his later industrial experience. For the employer it provides an excellent opportunity to observe and assess the graduate's qualities and capabilities.

20. The project can take many forms—in Annex C several are described. The number of graduates may range from 3 to 12, and the group might profitably include technicians and craftsmen. The article may be large or small—but it must be wanted, quickly and at a price. Experience has shown that despite initial fears on this score there is no shortage of projects. Perhaps not every firm could afford, either in manpower or money, to mount a good project of this kind; yet there is no reason, in principle, why firms should not collaborate in projects with each other or with the university or college. Indeed the educational establishment could be the setting for the project, although we are inclined to the view that considerable skill would be required to simulate precisely the industrial setting with its unexpected difficulties and unrelenting pressures.

(iii) *Specialised Technology Courses*

21. We are concerned to ensure that training is oriented towards the first job in a career and we characterise the job by its dominant function and by its field of engineering. The functions include those of:

(*a*) research and development

(*b*) design and engineering

(*c*) manufacturing

(*d*) commercial.

In Annex D we set out some of the activities associated with each function. In practice functions blend with one another and, although in general one will predominate in a given job, an appreciation of the others is essential and must be acquired in the course.

22. Our analysis of functions met with wide agreement among those whom we consulted, but we found it less easy to characterise the field of engineering. There is a broad distinction between those fields in which the product is of primary importance, and those where the techniques of production have more generality than the end product. We refer to these areas as Product Technology and Manufacturing Technology. Examples of the former come readily to mind—the technology of transformers or switchgear, of semiconductor devices, of the internal combustion engine or of the electron microscope. The difference of Manufacturing Technology is one of emphasis. It seemed to us that the technologies of mass production of small components or assemblies—light current equipment, switches, electric light bulbs, or domestic equipment, cutlery or plastic goods—might for training purposes best be approached from the viewpoint of materials and from the range of techniques available for their manipulation. Courses in Manufacturing Technology may well be oriented towards a particular product sector and they may indeed share some common features with Product Technology courses. Nevertheless we feel the broad distinction to be a useful one. We have given prior attention in this Report to Product Technology but Manufacturing Technology is equally important and we are now studying this in greater detail.

23. The aim of a course in, say, transformer technology would be to acquaint the graduate with all aspects of an enterprise committed to the design, manufacture and sale of that product. He would need some further engineering science and this might well be given by the staff of universities or colleges where advanced work and research in this topic is being conducted. In addition a substantial industrial contribution from practising engineers would be essential—in order to show the techniques whereby the scientific method and the pragmatic and empirical approach come together in the solution of a design and manufacturing problem. There would have to be instruction in the elements of organisation, measurement and control (management) of technical and manufacturing activities. Each main function would be covered, with opportunity for particular emphasis as appropriate. Relevance and realism—" warts and all "—would be the keynote: demonstrations of existing practices and case studies drawn from real situations must be used.

24. We envisage that such a course would be conducted at a Centre established by collaboration between an educational institution and one or more industrial units, the former providing a setting for teaching and instruction and the latter serving as a full scale demonstration " laboratory ". The Centre would be an organisational

grouping based largely on existing facilities; we do not wish to imply necessarily that a new physical entity comprising new or additional buildings, staff and equipment would be required. We believe that Centres of this kind can and should be formed by mobilising existing educational and industrial resources, the form to be determined by what is most appropriate in each case, having regard to existing facilities and to the indispensable part to be played by industry. These considerations, particularly in respect of industry, would seem to us to require generally that the Centre should be close to the industry it serves.

25. The Centre must serve national needs and not solely those of an individual undertaking. There must be enough students to make the course viable and to use teaching resources to the best effect. In many fields this may require only one Centre even though there be several manufacturers. A measure of self-imposed restraint may be necessary if wasteful duplication and proliferation are to be avoided.

26. In setting forth these principles we are aware of many major issues which arise. Means must be found to administer and finance the Centres and to define a sufficiently large and codifiable body of knowledge and "know how" for a given product to make a national course worthwhile and to attract sufficient support from industry and education. To examine these and related questions the Department has initiated on our recommendation two studies, one in the field of semi-conductor technology and the other in electrical switchgear. These studies are continuing in close consultation with industry. Further formal consultations and detailed discussions must follow and we recommend that these should be set in hand as soon as feasibility is established.

(iv) *Industrial Experience*

27. Employers and graduates alike have emphasised the value of industrial experience and this we endorse. Our concern is that it should be purposive and that the graduate should feel this for himself, should become involved and, above all, be given a measure of responsibility. We identify two main objectives—imparting information, and learning how desired results can be achieved by a complex enterprise—the firm—despite unforeseen obstacles and imperfections.

28. The graduate must familiarise himself with the structure of the firm and with the lines of responsibility and communication. He must see something of the activities of each department and become aware of the openings available to him. It is even more important that he should learn how far practice may depart from the ideal without frustrating achievement. His experience hitherto will have been to some extent theoretical and idealised. His industrial experience is like a controlled scaling-up process in which he encounters the imperfections and the factors beyond his control which emerge in real systems. This can only come by his being on the shop floor or in the office and it falls to his employer to provide him with good reason for being present. There can be no single pattern for achieving these aims; each employer must create his own.

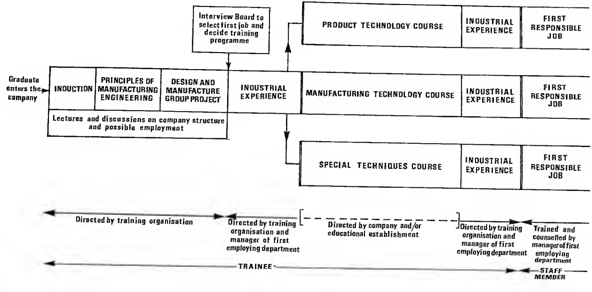
II. Assembling the Components

29. Our evidence and discussions have convinced us that there is scope for great flexibility in the way these elements are combined, and in their distribution and duration. The overriding consideration is that they should be planned and

FIGURE I

DESIGN FOR A MATCHING SECTION OF EDUCATION AND TRAINING

FOR THE UNIVERSITY GRADUATE ENTERING ELECTRICAL OR MECHANICAL MANUFACTURING INDUSTRY ON GRADUATION


Graduate enters the company
INDUCTION
PRINCIPLES OF MANUFACTURING ENGINEERING
DESIGN AND MANUFACTURE GROUP PROJECT
Lectures and discussions on company structure and possible employment
Interview Board to select first job and decide training programme
INDUSTRIAL EXPERIENCE
PRODUCT TECHNOLOGY COURSE
INDUSTRIAL EXPERIENCE
FIRST RESPONSIBLE JOB
MANUFACTURING TECHNOLOGY COURSE
INDUSTRIAL EXPERIENCE
FIRST RESPONSIBLE JOB
SPECIAL TECHNIQUES COURSE
INDUSTRIAL EXPERIENCE
FIRST RESPONSIBLE JOB
Directed by training organisation
Directed by training organisation and manager of first employing department
Directed by company and/or educational establishment
Directed by training organisation and manager of first employing department
Trained and counselled by manager of first employing department
TRAINEE
STAFF MEMBER

NOTES

1. General

Duration will vary with industrial sector, but should be flexible and minimal for stated objectives; probably between 1 and 2 years overall. Selective participation or entry at a later stage may be desirable for some trainees. Continuous pressure essential; persistent themes of time and cost throughout.

2. Induction

May vary from few days to several weeks; could be distributed over first few months. To be given in the firm or, for smaller companies collectively at an educational establishment.

Includes information:

—for the trainee (conditions of employment, opportunities, training programme);

—about the Company (history, establishment, products, policy);

—about the economic environment (relations with other companies, labour, Trade Associations, Research Associations, Central Government).

3. Principles of Manufacturing Engineering

12 weeks; might be reduced or omitted for some graduates e.g. Dip.Techs. Principles and skill appreciation, *not* workshop practice or skill acquisition; college- or industry-based.

4. Design and Manufacturing Project

About 12 weeks; 3-12 graduates, with or without craftsmen and/or technicians; whole cycle of ideas into hardware in industrial microcosm; under pressures of time and money. College- or industry-based but realism essential.

Smaller firms may require special arrangements e.g. by grouping.

5. Specialised Technology Courses

These courses are to give instruction in all aspects of the product; marketing, design, manufacture, organisation and management. Also to reinforce basic scientific knowledge where necessary and to teach industrial " know how ". Alternatively to teach all aspects and applications of special techniques for functions covering all products, e.g. production technology, research. Maximum 9 months, possibly less; may be subdivided—possibly between initial general material and later specialised, as offering facility for selective participation or partial overlap of courses. To be devised and mounted jointly, by an educational establishment and one or more industrial units; to meet national requirements by optimum deployment of industrial and educational resources; may be mounted at one or more Centres.

(i) *Product Technology Courses*

Oriented towards a product—e.g. transformers, semiconductor devices; instruction to cover main functions, as well as elements of organisation, measurement and control of technical and manufacturing activities.

(ii) *Manufacturing Technology Courses*

(Production Engineering)

Oriented towards techniques of production—manufacturing processes, materials and methods of manipulation, organisation and behaviour of systems, their control and measurement of their properties. May relate to specific product sectors, with some overlap with product technology courses.

(iii) *Special Techniques Courses*

Oriented towards advanced studies for specialised activities, probably in research and development e.g. high vacuum techniques, lubrication engineering; one or more short courses may be required.

6. Industrial Experience

To learn about structure and operation of the firm and of departments; and how a complex and imperfect enterprise achieves objectives; scaling-up of knowledge and abilities acquired in more idealised and controlled environment. Must be purposive effectively organised; graduate should realise this, and have responsibility and objective.

assembled as a composite whole relating to the development of a man's career and to his first responsible job, and this must clearly be evident to the graduate. Figure I shows how the elements might be combined for the university graduate entering industry on graduation. Within the main framework distribution is broadly determined by the point at which the first responsible post is chosen. Prior to this, training is introductory and generalised; subsequently it is closely geared to the job.

30. Training would begin with a period of induction, to give the trainee information of personal interest—conditions of employment, opportunities, the training programme—as well as about the company and industry and its national economic context. It might include some topics of industrial organisation and administration. The length could vary from a few days to several weeks, depending on how the talks and discussions are distributed. We have shown them as continuing in parallel with other activities

31. A short induction period would be followed by a course in manufacturing engineering, of minimum length required to meet the stated objectives. Careful planning, and efficient and coherent presentation, will encourage the trainee to maintain the momentum of his earlier studies. Relaxation at this stage will begin to forfeit his interest. This course leads naturally to the focal point of the first phase—the design and manufacturing group project. Here the trainee first meets in full the responsibility of achieving an objective despite limitations of time and money. Consciousness of cost and economy, which must permeate the whole course, first becomes dominant at this stage, and the trainee should reach it as quickly as possible. The experience thus gained can then be reinforced by a period of industrial experience which immediately follows.

32. This second phase would begin with a specialised course. In addition to the two kinds of technology courses already discussed we have shown a third alternative—a course in special techniques. This might deal with topics such as high vacuum techniques, thin film or single crystal-growing techniques, for the man entering research and development. Many excellent courses of this kind are already provided by universities and colleges. After completion of the specialised course we have shown a further final period of industrial experience prior to the first job. By this time the graduate would be expected to have a clear idea of his activities in this post and could select further experience in a complementary area not normally encountered in that job. For example, the man going into the design of heavy electrical equipment might spend some time on site, seeing how equipment is erected and commissioned.

33. We have deliberately avoided specifying the overall duration of the training period since we are advised that in many instances tbe traditional period of two years can and should be reduced. The length is likely to vary from one sector to another and must be worked out in each case.

Evidence and Evaluation

34. We would wish to make it clear that this enquiry is in no sense a statistically rigorous one. Nevertheless we consider it to be properly based on a critical appraisal of our own experience and on that of others—both employers and graduates—with whom we have had discussions. Its value must be tested by

further experience on the lines we have indicated, through feasibility studies and by mounting prototype courses. Ultimately, the general applicability of our analysis can only be revealed by the extent to which industry accepts and adopts the principles we have sought to expound.

(i) *Evidence from Discussions with Employers and Educationalists*

35. In our discussions with employers and educationalists we found broad agreement with the diagnosis of the problem and confirmation of the need to relate training more closely to the job. There is a powerful current of opinion in favour of new and revised forms of industrial training of graduates. For the university graduates it was recognised that this should be achieved by specialisation at postgraduate level following a broadly-based undergraduate course. The principles which we have sought to enunciate in order to guide this further specialisation and training for those entering manufacturing industry were widely endorsed.

36. Our evidence-discussions dealt in detail with the components of education and training set out above. The proposal for courses in the principles of manufacturing engineering and for the wider use of design and manufacturing group projects were approved almost without exception. The importance and value of industrial experience was also emphasised. It was our remaining proposal—for courses in specialised product technology to be given at national Centres—that provoked most discussion and raised a number of important issues which are discussed below. The aims of such a course were widely welcomed and supported and there was particular stress on their close teaching links with industry. It was agreed that the courses must be of the highest quality and status if they are to compete with other forms of postgraduate activity, and this must be recognised in the remuneration and support for those who participate—both student and teacher. The need for flexibility in these courses was stressed, not only to keep abreast of technological change but to make them widely accessible to all who might benefit from them—including the older graduate and non-graduate engineers and technicians. There were widespread and pressing requirements for additional provision of up-dating and retraining courses. While in the main this was regarded as an issue meriting separate and urgent consideration it was also foreseen that Centres might help in meeting some of these requirements.

(ii) *Evidence from Discussions with Graduates*

37. Discussions of our proposals were held with over 90 employees from nearly 20 manufacturing firms, through members of the Group and with the help of the Industrial Liaison Officers of the Ministry of Technology. Most of them were university graduates in engineering, mathematics, physics, or chemistry, although the groups included Diplomates in Technology and engineers with other qualifications.

38. The need for further training on entering industry was generally acknowledged and the Group's enquiry was welcomed. We were advised that any scheme proposed should avoid giving the employee the impression that he was returning to an academic setting, and must recognise the graduates' desire to make a positive and useful contribution, with early responsibility in the course of his training. The decision on the specialised field of engineering was seen as a major turning point and should be based on adequate experience. Because of this it was felt that there should be flexibility regarding the stage during the training period at which this decision was taken.

39. Detailed discussion of our example for a matching section showed that it might well be shorter than two years. The main components were agreed but in certain cases it was felt that some sub-division and change of sequence would be desirable. Some students, particularly from sandwich courses, could dispense with the manufacturing engineering courses, although a group project set in a realistic environment would be of value to all graduate employees in their training. Courses in Product Technology could in principle meet requirements for specialised instruction but some uncertainty was felt about the value of courses in Manufacturing Technology. The majority of graduates viewed the possibility of a formal qualification for successful completion of the course with indifference, but the view was widely held that it would be desirable that the course be acceptable as a step towards qualifying for membership of a professional institution.

40. These discussions and those held with employers and educationalists inevitably raised wider issues regarding the university degree course. This was regarded as valuable in giving a broad basis of fundamentals though certain more specialised topics had proved of little relevance or had quickly " dated ". Undergraduate laboratory work was frequently criticised as unhelpful or irrelevant. There was felt to be scope for bringing out more clearly the relevance of basic engineering science to real practice and for more contact with real engineering situations during the undergraduate course. This could be achieved to some extent by giving the principles of manufacturing engineering at the undergraduate level; and it was felt that such instruction might with advantage have replaced some of the " less useful " subjects taught. Without exception, university graduates spoke of almost complete ignorance, during their undergraduate time, of the nature and variety of industrial employment open to them. They were unanimous in urging closer links at all levels between the universities and industry.

(iii) *International Comparisons*

41. While we have not examined in detail the preparation of engineers for industry in other countries, we find that the problems we have encountered and the proposals we have made are not without their parallels elsewhere. On the one hand we note that even in Germany with its notable provisions for technological education through the Technische Hochschulen and Ingenieurschulen there has recently been growing concern with the " Engpass Konstruktion " or " design bottleneck "—the increasing dearth of design engineers with creative ability. It has been said that growing emphasis on an abstract and analytic approach in the education of the engineer has been at the expense of fostering synthesising ability in the solution of concrete problems. On the other hand the main features of our proposals find parallels in certain training schemes in the U.S.S.R. and the U.S.A. In these schemes —notably the Zavod—V.T.U.Z., and the General Motors Institute at Flint, Michigan—the complete education and training of an engineer lasts for 5-6 years after leaving school, divided between a general basic education given in the first three or four years and a subsequent period of specialisation oriented towards a particular product technology and provided jointly by industry and an educational establishment. A further account of these schemes is given in Annex E.

(iv) *Other Work on the Training of Graduates*

42. The education and preparation of the engineer and his induction into industry have been widely discussed in recent years. While the conclusions reached may in some cases have differed from our own we think it of value to include a brief bibliography (Annex F) of those studies of which we are aware, some of which we have taken in evidence.

Issues outstanding

43. The evidence we have received has raised the following important issues requiring clarification.

(i) *Finance*

Our proposals are based on the collaboration of educational institutions and industrial concerns and means must be found to ensure that the costs of financing staff, students and equipment are met in ways satisfactory to all concerned. Detailed analysis will be required for each course or Centre but we would note here two possibilities for assisting solutions on a national scale. The education and training to be given in the matching section is in effect training for employment, which has in the past been largely conducted by industry. The objectives we have outlined are consonant with the aims of the Industrial Training Act and we believe that the provisions of this Act should be used to facilitate the co-operation of education and industry in achieving them. We further note that the Science Research Council recognises within its responsibilities the support of postgraduate courses of instruction of relevance to industry, notably in its recent proposals for industrial studentships, in which industrial support will be combined with that provided by the Council. We hope that courses in specialised product technologies of the kind outlined above may qualify for the Council's support, as one way in which a higher proportion of the ablest graduates may be attracted into industrial employment.

(ii) *A Formal Qualification*

While opinion was divided on the question of a formal academic qualification to be awarded for successful completion of a specialised product technology course, it was widely felt that the course should count towards the training requirements for membership of a professional institution. Our discussions with the Council of Engineering Institutions have indicated that, in principle, the institutions would be prepared to consider this possibility. An academic qualification would have advantages only if it attracted the good graduate and served both for him and his employer as a measure of the value of the course. However, the skills and abilities developed on the course and the ways in which they would be acquired will not be readily susceptible to traditional examinations, and appropriate methods of assessment will need to be devised accordingly. Whatever solution is reached for individual courses there must clearly be regard to the national pattern if the courses overall are to attain comparably high status.

(iii) *Commercial Security*

We were advised that the need to maintain commercial confidence might restrict the content of specialised technological " know-bow " in product technology courses, and hence their value to individual firms. It might also limit the role of the local firm as a demonstration laboratory. While recognising this problem we believe it to have been exaggerated. The experience of certain firms has shown it can be overcome, and it has not prohibited progress of the feasibility studies. Courses would aim to give an appreciation of specialised technological practices broadly common to the product sector rather than attempt to convey in detail the accumulated expertise of a particular firm.

Related questions are whether such courses might act as recruitment channels for certain firms, or might become biased towards the practice and technology of a particular firm. On the first, employers felt that a graduate should be committed to a company before being accepted for a course, although there might be exceptions to this. To avoid bias, it was suggested that the course might be rotated between several centres at intervals of a few years; or might be subdivided between these centres, the graduate spending a period at each. These alternatives, it was argued, would have the added advantage of discouraging over-specialisation and "in-breeding" of expertise at a particular firm, college, or university. We see, in these proposals, some problems requiring further exploration.

(iv) *Research*

While recognising that an opportunity for research is needed to attract good teaching staff, we do not envisage that Centres would necessarily conduct research in the particular technology associated with them. Indeed the view was expressed in evidence that any shift of emphasis from effective and inspired teaching to research should be resisted as deflecting the true purpose of the Centre. Centres would be formed by drawing resources together temporarily. The need for flexibility of content, of participation, and perhaps of location would make their deliberate association with massive research facilities unnecessary and, as possibly an overriding consideration, undesirable. Most teaching staff should not be involved full time in the course, and should have opportunity to pursue their own work. Expertise in the subject of the course would be sought by inviting the occasional and regular participation of those expert in a particular field.

(v) *Smaller Firms*

Smaller firms make a major contribution to the Gross National Product of the U.K. and increased recruitment of able graduates into this sector could be of especial benefit both to productivity and to technological advance. Our evidence has indicated that smaller firms are likely to require specific incentives and particular arrangements to secure their participation in schemes of the kind envisaged here. The release of staff for teaching at the Centres, or for training over long periods, will require careful planning. Nevertheless the experience gained by the Scottish Electrical Training Scheme shows that smaller firms can collaborate in training arrangements, to the benefit of all. We recommend that these important problems should be further investigated, and the solutions to them closely supported by the financial provisions of the Industrial Training Act.

Immediate action

44. Industry's needs are urgent and we intend that our recommendations should point the way to further action that can be taken immediately, namely the establishment of more courses in the principles of Manufacturing Engineering, and of prototype Centres of Product Technology. There must be further consultation on the establishment of such Centres between Government Departments, the representative industrial organisations and the colleges concerned, the Engineering Industries Training Board, and the professional institutions. We recommend that discussions should be initiated as soon as possible.

45. We further propose to extend our enquiry in two ways:

(i) To examine a possible structure for a course in manufacturing technology:

(ii) To examine the requirements of the " user-maintainer " industries, e.g. electricity, transport.

We have already held preliminary discussion with those experienced in these fields. It is clear that there is sufficient content for a specialised manufacturing technology course, and that it is likely to be viable on a national scale.

46. Discussion with representatives from the electricity supply industry have revealed requirements for training that closely paralleled and at certain points—for example high voltage equipment or generating plant—overlapped those in product technology. There are fruitful analogies for education and training between the manufacturing and the " user " sectors, and further with the process industries—for example, the theme of " systems engineering ". We intend to pursue these, but it is already apparent that the general need to make training more purposive and to orient it towards the job are common to all these sectors.

Wider issues

47. Our enquiry raised several important issues which extended beyond our immediate concern with the postgraduate period. We record them here as matters relevant to the Committee's wider responsibilities for manpower resources in science and technology.

Education for Engineering in the Universities

48. The view was strongly presented, by young graduates particularly, that several of the elements of training we proposed could with advantage replace less relevant material in the undergraduate course. Manufacturing engineering was instanced, and we believe there should be further enquiry into the means of providing an element of practical contact with manufacturing engineering in or before the full-time degree course. We would note here the absence of any body which might serve as a focal point for discussion of curricula in higher education, in the way that the Schools Council does for school curricula.

Science Teaching in the Schools

49. A significant body of opinion saw in our enquiry implications for the teaching of science in the schools. They traced the difficulty of manning the functions of design and manufacturing to the inherent bias of the educational system towards favouring and developing the individual's powers of abstraction and analysis. It was felt that an alternative approach towards the teaching of science which could adopt a synthesising rationale and deal with the properties of systems and the deployment of natural resources might appeal to those at present opting for the arts or social sciences.

50. As revealed by the Page Report* there are already a number of significant developments taking place in the schools, to infuse the teaching of science with an appreciation of its relevance to creative applications in technology and engineering. We see in these the recognition of the value of an alternative approach and welcome the steps being taken by the Schools Council to introduce this approach more widely.

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*Engineering Among the Schools', Report by G.T. Page M.A., The Institution of Mechanical Engineers, August 1965.

Re-Training and Up-Dating

51. The starting point for our enquiry was the problem of devising a matching section of education and training between education and industry. We have here confined our attention to the newly qualified graduate. The problem recurs however at later levels and we are advised that there is need for a thorough-going enquiry into employer's requirements for up-dating and re-training. At all levels the problem presents two major facets:

(*a*) defining the requirements in terms relevant to education;

(*b*) improving communication between industrialists and educationists in order to meet these requirements.

The channels of communication between industry and education are numerous and arrangements do exist for employers to elaborate and make known their requirements. Yet, we are advised, the gulf persists. It must be bridged if the nation's technological momentum is to be maintained—and we suggest that it be made the subject of a further enquiry.

Summary of Recommendations

52. Within the field of our enquiry we recommend as follows:

(i) Industry and education should collaborate in devising " matching sections " of education and training designed to ensure the efficient conversion of the university graduate into an effective industrial technologist, and which will attract a higher proportion of the ablest graduates into industry (paragraphs 3-5).

As essential elements of this planned induction into industry:

(ii) There must be greater provision of short courses in the principles of manufacturing engineering (paragraph 17).

(iii) Industry should be encouraged to provide, in collaboration with educational institutions or by arrangement between firms, more training by " design and manufacture group projects " (paragraph 20).

(iv) There should be specialised instruction in specific product and manufacturing technologies; this instruction should be given in courses at Centres mounted and staffed jointly by an education institution and one or more industrial units in the sector they serve; the courses should meet national requirements and not solely those of individual undertakings, and should be provided by mobilising existing resources rather than by spending additional resources on any large scale (paragraphs 24 and 25).

(v) The Department of Education and Science and the Ministry of Technology should initiate as soon as possible formal consultations aimed at establishing, as pilot experiments, Centres of Product Technology in the fields of electrical switchgear and of semi-conductor devices, if studies now in hand show these to be feasible. (paragraph 26).

(vi) The provisions of the Industrial Training Act should be used to facilitate the co-operation of education and industry in achieving the aims of more effective professional training and increased recruitment into industry (paragraph 43(i)).

Report of the Sub-committee on Manufacturing Engineering

Committee on Manpower Resources for Science and Technology

Working Group on Engineering Training and the Requirements of Industry

Sub-Committee on Manufacturing Engineering

Membership

Mr C. L. Old (Chairman)	Chairman, Education Committee, Institution of Production Engineers
Mr J. Cherry	Department of Production and Industrial Administration, Cranfield College of Aeronautics
Mr A. D. Collop	H.M. Inspectorate
Professor J. Loxham	Department of Production and Industrial Administration, Cranfield College of Aeronautics.
Mr R. E. Stevenson	Engineering Industry Training Board.
Colonel A. L. Work	Technical Adviser on Industrial Training, Ministry of Labour.
Mr D. W. Tanner (Secretary)	Department of Education and Science.

Sub-Committee on Manufacturing Engineering

Report on

A Short Course in the Principles of Manufacturing Engineering

1. We were appointed in January, 1966,

> " To investigate for the Working Group on Engineering Training the formulation of a course in Manufacturing Engineering ".

The course, which would be an integral part of a larger programme of education and training envisaged by the Group, would convey in an organised way how materials can be manipulated into shapes that are needed, and which materials are best suited for a given purpose. As well as instructing in the basic technical principles the course should give the student sufficient practical competence to enable him to participate more effectively in his subsequent training.

Procedure

2. We were asked to report within three months. We have held five meetings and have obtained the views of individuals knowledgeable in this subject. We began by considering the aims of the course and the means for attaining them; these we exemplified in an outline of main topics on each of which we received expert advice. Further authoritative views were sought on this outline, within the time available, and we have had regard to them in preparing this Report.

Scope

3. We interpreted our task specifically within the context of the " matching section of education and training proposed by the Working Group. The course is thus intended for university graduates entering employment in the mechanical and heavy electrical manufacturing industries. It would be preceded by a short period of induction and introduction, and would be followed by further training and industrial experience e.g. by participation in a design and make group project. Lectures and discussions on company structure and possible employment would continue in parallel with the course.* Accordingly the course could be short—12 weeks or possibly less—to meet only the objectives as stated. It is not intended to provide instruction in design, or to give experience of involvement in team work under constraints of time and money. These important elements are provided elsewhere in the overall scheme proposed by the Group. With these restrictions the course will depend, for its impact and stimulus, on pace and presentation, which must be brisk and imaginative. We are advised that such a course is likely to be of value in its own right but would emphasise that if it is used alone or as part of another scheme provision should be made for these further objectives.

Aims

4. The first aim of a course in the principles of manufacturing engineering is to acquaint the student with the problems of turning ideas, as embodied in design, into hardware; with the processes and techniques for doing this—their advantages and limitations; with the materials at his disposal—their properties and performance; and with the way in which the requirements of design, manufacturing and cost interact. The second aim is to give some appreciation of the skills involved in these processes, together with sufficient practical competence required for subsequent training.

5. Together these aims are directed at providing a simple basic framework against which to set manufacturing problems subsequently encountered. There is in this an instinctive as well as a rational element and the course could also help to develop the " feel " that engineers have for the functioning of machines and the potentialities and behaviour of

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*See Figure 1 of the main Report.

materials, as well as providing background knowledge. With careful planning these aims could be achieved more efficiently than by the traditional random exposure to manufacturing processes and practice on the workshop floor. The interest and motivation of the graduate will be retained, while he gains confidence in what may be for him a new milieu.

Course Activities

6. Broadly, the first aim would be met through lectures, seminars, discussions and experimentation; the second through practical work. The aims, although distinguished here, are complementary and the course activities must be closely interwoven to stimulate continual interaction between practical problems and basic technical information. The course will not play its part in the " matching section " between the university world and the industrial situation if it merely combines university lectures with instruction in craft skills.

7. Much of the basic information may be given in lectures, and these might include brief mention of relevant theory to provide a link with the graduate's prior knowledge and a reasoned basis for practice. It should not be necessary to cover theory with which he should already be conversant; references, and possibly supplementary instruction could meet the needs of a minority from other backgrounds or disciplines, or of those wishing to go more deeply into a subject.

8. Discussions and seminars could encourage an open-minded and questioning approach to manufacturing problems and traditional solutions. They might begin from a particular component or device, analysing the materials of construction and methods by which it might be made, in relation to its functions and the theory underlying its action. These sessions and the lectures could be backed to some extent by experimental work. For example, the effects of major cutting variables on cutting forces, power requirements and surface finish could be compared using dynamometers while working on standard machines on the shopfloor. Experimentation could illustrate principles, and could show the relevance of data on manufacturing performance to selection of process or material as well as to design.

9. The second aim would be accomplished through practical work. At least half of the course would be devoted to this, with additional opportunity outside scheduled hours. Starting from a given design of specified dimensions and materials, the students would make articles chosen to give a wide range of experience with techniques, processes and materials. To acquire competence students would work individually and might, at the beginning, make a complete item on their own. They could progress to making, as a group, more complex articles requiring assembly, and introducing ideas of accuracy and finish. The practical work should be cross-linked with the basic instruction as widely as possible e.g. machine work with metrology, and with properties of materials. The bias may naturally be towards metals and metal-removal processes but this should be deliberately countered by using non-metals and other processes wherever possible.

10. These main features may need to be supplemented by some other activities. Practical work will require familiarity with engineering drawing and those lacking this will need instruction. This might be given by programmed instruction, a technique which could be used elsewhere, for example, in learning to set up and operate a machine. In specific instances technical films might be used to show details of methods or processes. Industrial visits, if brief and precisely oriented, with prior discussion of principles, could demonstrate particular processes not generally accessible.

Student, Staff and Location

11. The graduates entering employment in the sectors we are considering will be mainly mechanical and electrical engineers, with some physicists and mathematicians. Courses might also include arts graduates. Advantage might be taken of a variety of background, e.g. in seminars and discussions, but this might also require some additional instruction

early in the course. Courses, being intense and closely knit, would make considerable demands on staff and facilities, and the number of students per course should probably not be large. It was beyond our terms of reference to estimate the number of courses that might be required but they could be numerous and widespread, according to local demand.

12. The course must, in content and presentation, be at a level appropriate to graduates. Course tutors will be required to provide continuity, while specialist lecturers might be engaged for particular topics. Practical work would be supervised by trained instructors—experienced craftsmen whose understanding would enable them to relate practice to the underlying principles. Staffing of the course is the key to its success and requires particular attention—and perhaps even the provision of high level courses to prepare staff.

13. The course should be devised and operated jointly by education and industry, and there is scope for flexibility in location and in the degree of partnership. Classrooms and workshop space must be close together and could be in a college or an industrial unit, or provided jointly, depending on local resources. What is important is to set the course in a context as close as possible to production without interfering unduly with the day-to-day industrial activity. For example practical and experimental work might be done in an area of the shop floor not immediately engaged in manufacturing.

Course Contents

14. Materials science and technology will become increasingly important for the engineer. There could accordingly be two main types of course, oriented either towards methods and processes or towards materials. Either kind would have to incorporate substantial treatment of the other subjects and the difference would be mainly in approach and emphasis. The sectors we are considering call for emphasis on methods and processes, which accordingly predominate in our list of topics, given in Appendix 1. But a " materials theme " must run throughout and might be given:

(i) at the beginning of the course, by a brief review of materials from the general viewpoint of solid state physics;

(ii) in the main body of the course by considering methods and processes in relation to materials' properties, and by using non-metallic examples where possible, for illustration and practice;

(iii) towards the end of the course, by a section devoted specifically to materials from the viewpoint of manufacturing.

15. In a course oriented towards methods and processes, practical work could be done in these main phases:

(i) a simple article for the student to make on his own, giving experience in the basic machining operations;

(ii) a small assembly with components made and assembled by two or three students, introducing a wider range of operations and requiring attention to accuracy and finish;

(iii) a moderately large assembly that can be tested for functioning and performance when finished, with perhaps a dozen students contributing.

Examples of articles corresponding to these phases are shown in Plates 1 and 2. The aim in all these—and they could be extended as opportunity offered—is to give some competence and experience in a range of manufacturing methods and processes. There might be preliminary discussion on the design (and the drawings), materials and methods but decisions on these would not be required; experience in these aspects is to be given in the subsequent programme of training.

16. We list, in Appendix 1, some subjects and topics for a course oriented towards methods and processes. We have not attempted to specify the time spent on each, nor the order of treatment. The student should, however, begin early on practical work, within the first two or three days, and the order shown would allow this. Practical work and technical instruction should be closely interwoven and topics frequently cross-related. It would

probably be helpful to begin the course with a brief conspectus of contents and scope; and there might be more general topics such as Safety, which should be an integral part of the whole course.

Conclusion

17. The theme of this course is manufacturing, and its success in giving the individual student an appreciation of the principles and problems involved should be judged by his response and against his subsequent experience rather than by more conventional academic means. There can and should be great variety of example and emphasis within the main framework and the subjects we have suggested for inclusion are given mainly by way of example. These courses are intended to meet the needs of graduates and their employers and only close and continuing collaboration between education and industry can ensure that these requirements are met both in scale and content.

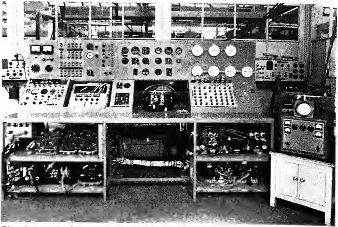

Plate 5. Autopilot Systems Test Rig

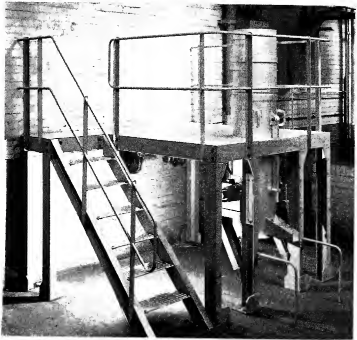

Plate 6. Small Foundry Cupola

Theoretical Analysis of Cutting Process	*Brief* treatment of Merchant's analysis and more recent developments—e.g. Oxley and Palmer, Boothroyd, Heginbotham (references may be sufficient).
Tool Life and Economics of Cutting	Significance of Taylor's Speed-Life relationship; optimum conditions for minimum cost, including " throw-away " tipped tools.
(*b*) *Plastic Flow*	These topics assume that students have knowledge of solid mechanics in the elastic range. Some time might be spent in revising three-dimensional yield criteria.
Bending	Introduction to plastic bending theory with special reference to spring-back prediction, residual stresses and their reduction. Progressive and continuous methods—their control, allowing for change in material properties. Stress/strain relationships, bend allowance and spring back; general press work, range and limitations: folding machines, brake presses.
Stretch Forming	Theoretical considerations of bending with applied tension with reference to elimination of radial spring-back; effect of friction; forming to double curvature; required material properties. Types of equipment and control techniques.
Deep Drawing	Conventional single and double action processes; stress/strain limitations, related tool geometry and force/stroke characteristics. Special rubber die and fluid die processes.
Spinning and Flow Turning	Comparison of the two processes and necessary equipment. Power and forces for flow turning. Hot extrusion, flow drawing.
Forging, Extruding and Wire Drawing	Introduction to mechanics of forging, extruding and wire drawing with frictional considerations. Machine selection. Material and design considerations, range of application, tolerances achievable. Forward and backward extrusion, slug preparation, typical components and materials, tool design. Hydrostatic extrusion for brittle materials.
Cold Rolling	Introduction to mechanics of rolling strip material. Neutral plane, distribution of normal roll pressure, effect of variations in front and back tension, roll force, roll torque, frictional considerations. Manufacturing techniques, material and design considerations, tolerances achievable.

High Energy Forming	Introduction to deflagrating and detonating explosives and their decomposition characteristics. Comparison of initial deformation under adiabatic and isothermal conditions. Use of high velocity tooling and machines. Magnetic forming.
(c) *Material Joining*	
Classification of joining processes for metals and non-metals	Mechanical, welding, adhesives: relative costs.
Survey of welding, brazing and soldering processes	Slag-shielded processes: shielded metal arc, submerged arc, electro-slag. Inert gas-shielded processes: tungsten-inert gas, metal-inert gas (argon, carbon dioxide). Pulse welding. Oxy-gas processes: welding, cutting. Brazing and soldering. Resistance welding. Electron beam, laser, plasma processes. Pressure welding: roll bonding, friction welding, ultrasonic welding.
Metallurgical significance of welding	Thermal cycle; weld defects; weldability; cracking; brittle fracture.
Design for welding	Types of joint, properties and performance of welded joints; codes of practice, rules of construction, specifications.
(d) *Powder Methods*	
Powder metallurgy	Basis of process; manufacturing techniques; material and design considerations; tolerances achievable.
(e) *Forming from Liquid Phase*	
Casting processes	Sand casting, centrifugal casting, investment casting, die casting, permanent mould casting, shell mould casting. Material and design considerations, tolerances achievable.

II. Treatments	
Heat Treatment	Annealing, hardening, tempering, stress relieving, case hardening, nitriding.
Surface treatment	Chemical and electro-chemical corrosion, prevention and control, surface protection (relate to materials section).

III. Metrology	
Standards of length	Basis of metric and yard measuring systems. Calibration of end and line standards.
Angular measurements	Units, angular standards, measuring equipment.

Straightness and flatness	Comparative and direct measurement.
Geometric shape	Roundness.
Surface finish	Establishing a datum, numerical value, measurement of surface finish.
Manufacturing and design requirements	Universal interchangeability, selective assembly, matched fits, choice of manufacturing tolerances, limits and fits, geometric tolerances. Impact of accuracy and surface finish on subsequent fitting and assembly procedures.
Inspection organisation	Integration of measuring technique and manufacturing process.
IV. Communication in Engineering	Engineering drawing and orthographic sketching; comparison with other methods of communication between designer and manufacturer.
V. Production Engineering: Elementary Principles	Brief introduction to topics of general relevance to all functions—R and D, manufacturing or product fields—as background to methods and processes: techniques of method study, rate fixing, control, " idle time ".
B. Materials	
Background theory	Properties as stemming from physics and chemistry of the solid state; types of bonding in solids; crystals and molecules.
Range and typical usage	Natural and synthetic materials. Metals and alloys. Non-metals; cements, ceramics, glasses, plastics, rubbers, wood. Compound materials; bi-metals, fibre reinforcement, cermets, laminates.
Properties	Physical and chemical properties relevant to manufacturing and function, shear strength, yield strength, deformation and flow under heat and pressure; bulk and surface properties; changes in properties induced by manipulation, treatment and use.
Economics	Relative costs of natural and synthetic materials in relation to strength, finish and processing.
C. General	
I. Safety	Attitudes to safety; general safety precautions in shopfloor practice; industrial hygiene; relevant sections of the Factories Acts.

Annex B

Persons Consulted in the course of the Enquiry

Mr R. G. Bellamy	Deputy Industrial Relations Adviser, Electricity Council.
Mr G. L. H. Bird	Education Officer, Machine Tool Trades Association.
Mr J. F. G. Bland	Education and Training Officer, Central Electricity Generating Board.
Mr W. Woodford	Secretary, Institution of Production Engineers.
Mr F. W. Cooper	Education Officer, Institution of Production Engineers.
Mr D. J. Crowther	Manager, Group Personnel Services Power Group, Associated Electrical Industries Limited.
Mr C. H. Flurscheim	Director of Engineering, Power Group, Associated Electrical Industries Limited.
Mr R. F. Marshall	Central Education Manager Associated Electrical Industries Limited and University Liaison Officer.
Dr J. R. Mortlock	Chief Systems Engineer, Power Group, Associated Electrical Industries Limited.
Mr G. B. R. Feilden	Group Technical Director, Davy-Ashmore Limited.
Dr H. L. Haselgrave	Principal, Loughborough College of Technology.
Mr A. Hirst	Education and Training Executive, S. Smith and Sons.
Professor K. Koenigsberger	Professor of Machine Tool Engineering, Manchester College of Science and Technology.
Colonel B. H. Leeson	Chairman, The Electrical and Electronic Manufacturers Joint Education Board.
Mr T. A. Swindon	Director, Engineering Industry Training Board.
Mr F. Metcalfe	Chief Education and Training Officer, Engineering Industry Training Board.
Mr R. E. Stevenson	Principal Training Officer, Engineering Industry Training Board.
Major General J. E. C. McCandlish	Secretary, Scottish Electrical Training Scheme.
Miss P. K. Piercy	Ministry of Technology.
Mr A. L. Stuchbery	Technical Director of Machine Building, Metal Box Company.
Professor S. A. Tobias	Head,, Department of Mechanical Engineering, Birmingham University.
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The opportunity was taken to have the apparatus re-designed and rebuilt by a team consisting of one graduate in training and five non-graduate apprentices.

A time limit of 15 weeks was set and material costs were to be strictly limited. All design and manufacture was carried out by the team members at a final materials cost of approximately £50. After an acceptance test which revealed some but by no means many errors of planning and design the equipment went into regular use. [Plate 5].

As this project was based on redesign of existing equipment rather than on an original design this example was not quite so rewarding as some. It does show however the feasibility of such an exercise where there are only one or two graduates in training in any one firm. Within its limitations it proved to be a valuable piece of training.

Small Foundry Cupola

The firm's training school required a cupola for the foundry, capable of melting an 80lb charge of ferrous metal. The pattern of this project followed commercial procedure in that a tender, specification and estimate were prepared, by a graduate trainee, and discussed with the " customer ".

Detailed drawings were prepared and production was carried out by a team of 1 graduate, 1 sandwich course undergraduate and 2 trainee technicians with some assistance from craft apprentices. Production time was 2 months.

Materials for the project, including the supporting structure and platform, cost about £150. The overall cost of the work amounted to some £700. A relatively simple example but worthwhile experience for those who took part. [Plate 6].

Further Examples of Group Projects

(i) A test rig was required for the development of a new range of Rotary Actuators and second-stage gearboxes. A mixed group of eight graduates, including an economist and an Industrial Engineer, completed the task in 12 weeks, after only 17 weeks previous training. The cost of the 711 components with a total weight of 3 tons, was about £750.

(ii) Apparatus to study the flow of gases through the exhaust value of a diesel engine and the effect of altering the shape of the valve port.

(iii) A Lathe Dynamometer to demonstrate and measure the effects of varying the angles, feeds, speeds, etc., of a particular tool on its performance and hence to discover the optimum conditions of operation of the tool. This project was carried out by two graduates.

(iv) A simple Cross Polariscope to demonstrate stress concentrations. This project was carried out by a small group of graduates qualified in mechanical, electrical and instrument engineering.

(v) A Dynamic Balancing Machine suitable for small rotors, armatures, shafts, etc. This project was carried out by four graduates in eight weeks.

(vi) A small, highly powered, Steel Rolling Mill was needed for research work. In this project third-year students at a university designed the equipment, second-year students made the detailed drawings and later the same second-year students spent two months in industry manufacturing equipment.

(vii) A Shell Moulding machine for use in the special castings section of a foundry.

(viii) A Demonstration Rig to show the basic principles of position control systems with velocity feed-back. Two sets are in use at a university.

(ix) A calibration set for capsules providing a digital read-out.

(x) Handling gear to facilitate the building of a 350 KVA turbine-generator set in a training school.

Annex D

Analysis and Description of Functions performed in Manufacturing Engineering

1. *Commercial*

Intelligence and Market Research	Supply of market information and potential customer requirements-liaison with existing customers—fostering of business—collection of detailed information for preparation of tenders, etc.
Enquiry and Tender	Preparation of tenders and handling of potential customer enquiries —liaison with technical departments.
Product Contracts	Execution of contracts (accepted tenders)—Placing of orders on Group works and other suppliers—planning and progress of contracts and liaison with other contractors involved—Handling of customer queries—Collection of payments etc.

2. *Design and Engineering*

Specification	Translation of customer's problem into a technical one and solving it. Definition of main parameters of units of equipment required, e.g. overall size and shape, main stresses, temperatures, voltages, currents, etc.
Design	Achievement of optimum containment of the defined parameters. Reconciliation of conflicting demands of time, cost, technical and manufacturing requirements.
Drawing Offices	Detailed definition of size, shape, material and number required for each component.

3. *Research and Development*

Research	The acquisition and codification of new knowledge to enable improvements to be made in existing products and to point the way to new products. Laboratories may not be essential. Much information can be acquired from reports and publications and tests on equipment in service. Industrial research must be specific to industrial needs. Academic research can be the pursuit of knowledge for its own sake.
Development	The validation of new knowledge and techniques in practice by observation of completed equipment operating in its environment or the testing of prototypes or parts of prototypes in real or simulated environments.

4. *Manufacturing*

Preparatory Work	Nature of materials, design of machine methods. Choice of process of machine jigs and tools. Cutting and forming technology. Schedules of operators and times and estimated costs, etc. Manufacturing programmes. New developments and processes. Optimisation of use of existing capital resources. Balance of manufacturing load throughout Group. Introduction of new methods and processes. Plant replacements and extensions.
Operations	Execution of production programmes in workshops; this includes support services of production control, progress, recording, test and inspection.
Erection and Commissioning on site	The placing of the completed equipment in the hands of the customer in satisfactory operating condition. This may range from the construction of a power station to the delivery and installation of a domestic appliance.

Annex F

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Printed in England for Her Majesty's Stationery Office
by McCorquodale, London

HM 1069. Dd. 126297. K.32. 7/66. 3309.